**An Overview of Renewable Energy and its Effects on Wildlife and the Environment**

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**Renewable Energy and its Effects on Wildlife and the Environment**

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**Abstract**

As concern over greenhouse gas (GHG) emissions from conventional fossil fuel sources rises, energy developers look toward renewable resources as prime candidates for “cleaner” and “greener” energy production. This paper provides an overview of the main environmental and wildlife effects of five of the major renewable energy sources: wind, solar, geothermal, biomass, and hydro. Examples of the effects of pollution, habitat degradation, land use, species mortality, and Endangered Species Act (ESA) listed species are discussed. Avoidance and mitigation suggestions are reviewed.

Before-after-control-impact assessments and habitat conservation plans can aid a developer in siting of a renewable energy project. The developer must weigh the economical and environmental costs of a project. Mitigation efforts should be made before construction, however, these efforts are not always clear and can be lost without proper enforcement. Early and continuous contact between developers and regulatory agencies can prevent increases in project time. Ignoring species and environmental protection guidelines up front can cause increased costs later on to mitigate the disturbances.

Areas lacking research and viable data are addressed. Additional research is needed on species located in energy-rich habitats, particularly for ESA-listed species and species that are believed to be strongly affected by the new development. Currently, plans for carbon-based energy production are duplicated and utilized for environmental and species conservation with regards to renewable energy. In order for wildlife and environmental specialists to effectively plan for renewable energy developments and perform effective mitigation efforts, additional rigorous studies will need to be conducted. These plans will need to be tailored to each renewable energy source in order for environmental planners to recognize the differences between them.

**Introduction**

The world is demanding “cleaner” and “greener” energy sources that limit greenhouse gas (GHG) emissions and are more eco-friendly to the species in the local environment (Reimer and Snodgrass, 2010). There is no doubt that the net amount of GHG emissions from renewables such as wind, solar, geothermal, biomass, and hydro is less than that of conventional sources which exploit fossil fuels. In comparison to conventional energy sources, little research has been done to explore ecosystem degradation caused by renewable energy development, plant operation, and resource extraction. This may be due to the sudden interest and rush in renewable development in recent history. It would be beneficial to fully understand ecosystem impacts of each renewable source prior to development and operation in order to better avoid ecosystem degradation and understand what mitigation efforts will be needed in the future.

Reimer and Snodgrass (2010) explain that most studies of energy effects on ecosystems are based on the development of oil and gas facilities. In some cases, such as wind farm development, conventional energy infrastructure construction and management involves activities similar to that of renewable energy infrastructure development. This leads to the question: *Is renewable energy as environmentally friendly as was previously hoped*? According to Jager and Smith (2008), one of the greatest barriers to renewable energy progress is putting a value on ecological benefits. The other two major barriers are understanding ecological effects of human-induced environmental changes and providing incentive for power producers to care about these changes (Jager and Smith, 2008).

Economic values of renewable energy are determined by costs associated with development and operation. In some cases, renewable energy is a viable economic option. One study in the northwest United States estimates that coal-generated power costs approximately 5 cents per kilowatt hour, whereas wind costs approximately 4 cents, hydropower 3 cents, and tidal energy 20 cents per kilowatt hour (Ma, 2011). Costs of environmental damages are difficult to quantify and should be considered in determining the future direction of resource extraction and/or utilization for energy.

Several measures exist to aid developers in evaluating energy sites. Programmatic Environmental Impact Statements (PEIS) typically consider future actions that may cause GHG emissions, carbon sequestration, and climate change. Climate change alters the niches in which species live and threatens those with limited adaptability. The ability to quantify these climatic impacts in relation to energy production is currently lacking. Impact assessments of specific effects of human activities and levels of significance are, therefore, unknown (USBLM and USFS, 2008). Shaffer and Buhl (2016) explain that before-after-control-impact (BACI) assessments are the most common evaluation practice to determine the impact that energy infrastructure has on wildlife. BACI assessments are considered optimal for studies that require observation. Displacement designs for behavioral studies may display erroneous results due to the “minimal magnitude of the effect, poor precision of estimates, and lack of study design allowing for strong inference assessments.” Most displacement studies are short-term and do not include BACI assessment designs. Including characteristics such as multi-species approaches, long-term studies, and designs that offer strong inferences develop better quality results. The BACI assessment using displacement distances is particularly useful in species-specific behavior determination if prioritizing landscapes based on species conservation is the goal (Shaffer and Buhl, 2016).

Energy developments and their related infrastructure management practices cause habitat disturbances that are similar for both renewable and nonrenewable resources. Typically, impacts include potential releases of hazardous materials, direct and indirect injury or mortality, noise interfering with species habits, introduction of invasive species, and fragmentation of habitats. Noise interference can alter native population balances. Fragmentation may increase predation, disease, or drought susceptibility, separate populations, and limit genetic diversity through separating breeding groups. Attraction to, or displacement from an energy development site depends on the species sensitivity, most of which are highly sensitive to disturbances. For example, wind farm studies have shown that a certain few species which historically thrive in human infiltrated areas, as well as species that benefit from manmade materials, were able to withstand the infrastructure development changes. Wind and solar farms tend to encounter issues in development from species that have already been listed on the Endangered Species Act (ESA) whereas geothermal development has directly resulted in or contributed to numerous rare species becoming listed (Reimer and Snodgrass, 2010).

Land use for renewable energy is extensive and will compete with agriculture, forestry, and urbanization uses within the United States and throughout the world. The earth has less than half of the cropland per capita needed for a diverse diet and adequate essential nutrient supplies. According to Pimentel (2008), the United States has utilized the maximum amount of its prime cropland for food production per capita. Estimates indicate that approximately 795 million people in the world were undernourished in 2014-2016 (FAO, 2015). The amount of land needed for renewable energy will continue to compete with critical space needed for agriculture. This is most concerning for biomass production, as agricultural land that was once used for food production is shifted to energy production (EESI).

As stated by Glassley (2015), “The environmental impact of converting energy to electricity or some other useful form inevitably disturbs the environment. For this reason, it is imperative that aggressive, scientifically based monitoring, analysis, and mitigation efforts be considered an integral part of any energy development. The importance of renewable energy resources such as geothermal is that their environmental impacts can be minimal, if properly managed.”

1. **Wind Energy Effects on the Ecosystem**

Wind energy utilizes the heating of the earth’s surface, which causes movement of air in the earth’s atmosphere. Turbines are mounted at 30 meters or more above the earth’s surface to capture energy from the faster, less turbulent wind. Two or three propeller-like blades are mounted on a shaft to form a rotor. The pressure drop between the upper and lower surfaces causes the rotor to turn which causes the turning shaft to spin a generator, creating electricity. A wind turbine produces an average of 1.67 megawatts of electricity and utilizes an average of 135 meters of vertical air space. Environmental benefits to wind energy production over carbon-based energy include no greenhouse gas emissions such as carbon dioxide, no primary pollutant emissions of sulfur dioxide and nitrogen oxide, no particulate generation, no water resource use, and no mercury emissions (Reimer and Snodgrass, 2010).

Development of a wind farm does require site testing, construction, operation, and decommissioning. During site testing, meteorological towers with weather instruments as tall as 165 feet, are installed to determine site quality. Once the site is approved through permits, one to three acres must be cleared for each turbine (Reimer and Snodgrass, 2010). Offshore wind facilities, which are do not currently exist in the United States, require additional space because of their bigger blades and turbines (Union of Concerned Scientists, 2013). Construction involves site grading, vegetation removal from construction lay-down areas, excavating for tower foundations, turbine installation, and construction of control buildings, electrical substations, and meteorological towers. Decommissioning of a wind farm requires similar activities to that of its construction (Reimer and Snodgrass, 2010).

There are very minimal environmental impacts from wind energy aside from habitat and species degradation. Unlike solar energy sites, water use is not a major concern at wind energy sites. Water is used in the manufacturing process of the wind turbines, but this is common to all manufacturing processes. Wind turbine manufacturing and associated development and operations are responsible for minor emissions of greenhouse gases. It is commonly estimated that these emissions are between 0.02 and 0.04 pounds of carbon dioxide per kilowatt-hour. In comparison, coal-generated energy produces between 1.4 and 3.6 pounds of carbon dioxide per kilowatt-hour (Union of Concerned Scientists, 2013).  Hydraulic and insulating fluids as well as lubricating oils used on the turbines are used in small quantities. Unlike other renewable energy sources, ground or surface water contamination is not of high concern for wind energy (Wind Energy Development Programmatic EIS). A rare earth element, neodymium, is used in the permanent magnets of some types of wind turbines. The magnets are installed in the generators or motors, which are used to turn mechanical energy into electrical energy. The extraction of radioactive neodymium causes both pollution and raises environmental concerns regarding mine site reclamation (Zepf, 2013).

Construction activities result in habitat disturbance and fragmentation. Physical disturbances from construction are typically limited to five to ten percent of the overall development site, which includes the footprint of the turbines and other aforementioned facilities. Reimer and Snodgrass (2010) suggest that noise and dust caused by construction and habitat fragmentation may have effects that disturb a greater area, causing protected species to leave the degraded habitat and disturb their foraging, mating, and nesting practices. The authors explain that the science of wind energy impacts on some species has not advanced to the current state of wind farm development.

Wind energy production affect species both directly and indirectly. One direct impact of energy production is species avoidance of the site due to human infrastructure. Indirect impacts include habitat fragmentation, loss, or degradation, increased predation, as well as effects from the movement and noise created by the turbines (Reimer and Snodgrass, 2010). In a 2008 study by Kikuchi at the Altamont Pass wind farm site in Spain, ground squirrels were determined to be more vigilant in comparison to a similar site without wind infrastructure. The study confirmed that different levels of noise affected the behavior of the squirrels. Other species are also affected by noise changes. Bird population density is greatly reduced when continuous noise levels are 40 db or higher (Reimer and Snodgrass, 2010). Visual disturbances alter species behaviors as well. Rotating turbines create an effect that is known as “shadow flicker,” which causes brief glimpses of shadows when light is constrained past the turbines through trees or other objects. Shadow flicker may simulate the approach of avian predators and cause habitat avoidance (Reimer and Snodgrass, 2010).

As turbine numbers increase on a site, bird mortality increases. Increased turbines cause additional collisions with the blades, an increased likelihood of electrocution from more power lines, and an increase in collisions with related structures. Bird species that may be susceptible to collisions include ESA-listed species such as the “whooping crane, northern aplomado falcon, southwestern willow flycatcher, Mexican spotted owl, piping plover, and least tern (Reimer and Snodgrass, 2010).” Species susceptibility to collisions is skewed based on which species are more tolerable of wind farm development or even attracted to the development (Reimer and Snodgrass, 2010).

A study by Vanermen et al. (2015) on seabird displacement from an offshore wind farm at the Belgian Bligh Bank revealed that many gull species were attracted to the facility. The lesser black-backed gull and herring gull experienced increases by factors of 5.3 and 9.5, respectively. The authors explain that increased attraction may be due to an increase in roosting sites. In addition, disturbance in the range of wind turbines has been shown to increase prey abundance (Reimer and Snodgrass, 2010). At the Belgian site, the introduction of hard turbine foundations in what was once a soft-bottom marine ecosystem resulted in the development of hard-bottom communities of species. This communal development, called the “reef effect” resulted in the attraction of associated fish that are forced to the surface by water turbulence, creating a buffet for predators such as the gulls (Vanermen et al., 2015).

Reimer and Snodgrass (2010) state that an average of 2.19 bird-related deaths are caused by a single turbine every year, which includes older turbine technologies that result in greater fatalities. Without these older turbines included, yearly bird deaths per turbine decreases to 1.83. This statistic may seem inconsequential, but considering the amount of turbines in the United States, it is quite significant. According to the American Wind Energy Association, the United States currently has over 52,000 wind turbines (AWEA, 2016). If these turbines only use newer technology, this would mean that just the wind turbines themselves cause an average of 95,160 bird deaths each year in the United States.

Kikuchi (2008) explains that mortality risk is dependent upon several factors. Vision is an issue in that avian species that are crepuscular or nocturnal are less likely to detect and avoid turbines. Turbines located on the ends of rows or more isolated from other turbines are more dangerous than turbines located inside of the clusters. Birds recognize wind farms as obstacles to avoid, but may not recognize where the obstacle ends due to their mediocre sense of depth perception. Mortality rate may be higher in locations with several larger, less agile species such as swans (Kikuchi, 2008). Barrios and Rodríguez (2004) studied two wind farms in the Straits of Gibraltar, which contains a vital migration bottleneck between Europe and Africa. The authors found that only a small fraction of migratory birds were affected by the turbines because they were not situated within the direct flyways. Behavioral observations and migration route mapping can aid in avoidance of these flyways (Barrios and Rodríguez, 2004).

Large raptor species are very vulnerable to additive mortality because they are rare, long-lived, and have low reproductive rates (Kikuchi, 2008). Many wind farms in Spain were built on topographical bottlenecks where migrating and local birds must navigate through an area confined by mountains and ridges. The Navarre wind farms have caused the death of 409 vultures and 29 eagles in a single year. The Altamont Pass in California has experienced low mortality rates but high collision rates due to the large number of wind turbines at this location. The turbines within the Altamont Pass are responsible for the deaths of approximately 80 golden eagles and 400 griffon vultures annually. Collision mortality is suspected to be the reason for the dramatic decline of raptor species in this region (Kikuchi, 2008).

Other species of flight are of environmental concern, depending on where the wind farm is located. In the eastern United States, forested ridge tops are visited by bats during their migratory journey. In this location, bat fatalities dramatically range from approximately 15.3 to 55.3 bats per year (Reimer and Snodgrass, 2010). In other, less bat-populated areas of the United States, fatalities range from 0.8 to 8.6 bats per year. Reimer and Snodgrass (2010) note that an earnest effort of surveys of bat mortality from wind farms had only begun in approximately 2008 and that direct collision causes less than half of all bat deaths. Bats are drawn within a meter or two of the blades, possibly due to their roosting instinct, which causes a sudden drop in air pressure and hemorrhage to the lungs, or barotrauma. Barotrauma is the leading cause of mortality of bats in the vicinity of wind farms. Although more research is needed, it is suggested that increasing the minimum wind speed necessary for turbines to begin turning may decrease bat mortality by 56% to 92% (Reimer and Snodgrass, 2010).

The Beech Ridge Energy Wind Project in Greenbrier and Nicholas Counties, West Virginia, plans to implement a habitat conservation plan (HCP) to minimize the impacts of incidental takes on the endangered Indiana and Virginia big-eared bats. The HCP includes “1) constructing fewer turbines; 2) relocating turbines greater distances from bat hibernacula; 3) reducing risk to bats when they are active at low wind speeds by raising turbine cut-in speeds (the wind speed at which turbines begin generating electricity) during bat fall migration; 4) further reducing risk to bats by fully feathering turbine blades so that they barely move at wind speeds below the cut-in speed; 5) implementing turbine feathering and cut-in speed research to determine effectiveness of the changes in operational protocols; 6) monitoring bat mortality for the life of the project to ensure that biological goals are being met and that take limits are not exceeded; and 7) implementing off-site conservation projects designed to benefit the covered species by protecting and managing key habitats in perpetuity (EPA, 2013)”

One of the greatest species concerns for wind energy developers in the western United States associated with endangered species habitat fragmentation. The greater sage-grouse relies on large, intact areas of sagebrush habitat for both food and shelter in order to maintain its population. Sagebrush habitats are commonly located in areas that are suitable for wind farm development and as of 2010 the greater sage-grouse had been extirpated from approximately 50% of its native habitat. Future wind turbine site surveying includes most of the sage-grouse’s remaining natural range. It is estimated that the sage-grouse population has declined from 45% to 80% since 1965 (Reimer and Snodgrass, 2010). In 2010 the U.S. Fish and Wildlife Service (FWS) designated the greater sage-grouse as a candidate for Endangered Species Act (ESA) listing. The Sage Grouse Initiative was launched by the Natural Resources Conservation Service in 2012. Since then, it has been successful in increasing the greater sage-grouse population to sustainable numbers (USDA-NRCS, 2015).

Shaffer and Buhl (2016) expressed that statistical designs to evaluate the effects of wind farms on wildlife are neither rigorous nor numerous. Their team conducted a BACI assessment on wind farms placed on native prairies in North and South Dakota to determine the extent of wind turbine effects on breeding grassland birds. Nine species were surveyed for immediate (1 year after construction) and delayed effects (2-5 years after construction), seven of which were found to be displaced due to the turbines. The authors were not surprised that Vesper Sparrows and Killdeer showed resiliency to the new wind farm. Vesper Sparrows are typically tolerant to disrupted habitats and Killdeer prefer gravel substrates for nesting purposes. Killdeer were found to become more populous at the study site after the wind turbines were developed. Delayed displacement was observed for several species due to breeding site loyalty, e.g. species would return 1 year after construction but would not return in future years. Sustained displacement (displacement continuing from 1 into 2-5 years after construction) mostly occurred within 100 meters of the turbines.

Although commonly associated with wind farms, birds and bats are not the only species affected. Another species highly affected by wind turbine development is the ESA-listed desert tortoise. The tortoises experience a loss of habitat from the construction of roads, housing, and wind farm development. A proposed project in Las Vegas, Nevada called the Searchlight Wind Project was located directly in the desert tortoise’s habitat and nearby a U.S. Bureau of Land Management (BLM)-designated Area of Critical Environmental Concern (Reimer and Snodgrass, 2010). The project site contained the highest populations of desert tortoises and golden eagle nests in Nevada. In a federal court case in 2015, the project was terminated on the basis that the Interior Department did not properly evaluate the potential impacts to the desert tortoises and golden eagles in the environmental impact statement (Streater, 2015).

1. **Solar Energy Effects on the Ecosystem**

Solar energy is converted to electricity by either concentrated solar power (CSP) or photovoltaics (PV). Concentrated solar power utilizes mirrors to concentrate the sun’s radiation to heat a liquid or gas which is then used for power generation of steam-driven turbines. CSP is the older, cheaper, and more proven technology and typically consists of either trough systems, power towers, or dish/engine systems. Trough systems concentrate solar energy using U-shaped mirrors to heat oil which then boils water to create steam. Power towers concentrate solar energy on a receiver (usually molten salt) on top of the tower using flat mirrors.  Molten salt can be stored for a number of days or it can be used immediately to create steam. Dish/engine systems concentrate solar energy on an engine with enclosed cylinders (containing either helium or hydrogen gas) by using mirrors that line the dish. The expansion of the gas in the cylinders drives the generator pistons to make electricity (Reimer and Snodgrass 2010).

Photovoltaics is a newer, more expensive technology that requires additional research and development. Photovoltaic cells absorb solar photons that are radiated from the sun. Semiconductor atoms (silicon) of the PV cell receive energy from the photons which then strip electrons from atoms. The organization of silicon allows for positively charged and negatively charged types, creating a naturally insulted electrical field (Physics.org). Photovoltaic cells are combined on panels called arrays which are then combined until the desired generation capacity is reached (Reimer and Snodgrass, 2010). Photovoltaic cells reach efficiencies of roughly 25% (Pimentel, 2008). Additional developments to enhance electricity production, such as concentrators, are currently in testing stages (Reimer and Snodgrass, 2010). PV cell durability must be improved and production costs must be cut in order for PV cells to be economically feasible (Pimentel, 2008). Concentrator Photovoltaic (CPV) technology allows for concentrated optics that reduce the cell area and allow for the use of high-efficiency cells. CPV technology has the potential of providing a levelized cost of electricity competitive to CSP and standard flat-plate photovoltaic technology for some areas. Record efficiencies of 44.4% and 46% for triple- and four-junction solar cells were achieved by Sharp and Fraunhofer ISE (Philipps et al., 2016). The National Renewable Energy Laboratory (NREL) continuously seeks to boost solar cell conversion efficiencies, lower the costs, and improve the reliability of these systems. Perovskite solar cells are a newer technology that have seen major efficiency increases over the past two years (NREL, 2016). This technology is advantageous due to its “thin film solution processability, applicability to flexible substrates, and being free of liquid electrolyte” (Ahmed et al., 2015). Despite rapid progress in Perovskite performance, continual research is needed to fully understand its structural and electronic properties (NREL, 2016).

Solar farms require a vast amount of land and their introduction causes ecosystem disruption. On average, eight to sixteen acres are utilized to produce one megawatt of power (Reimer and Snodgrass 2010). Estimates for land use of solar farms are calculated using three metrics that are difficult to compare and vary by as much as 4 orders of magnitude (0.042-64 m2/MWh) (Horner and Clark 2013). These authors created a harmonization process that reduces the variation to 2 orders of magnitude [5-55 (m2y)/MWh] but variability cannot be reduced further due to technology and location factors. These key factors that contribute to the variability of solar land use are insolation, packing factor, capacity factor, and system efficiency. Insolation refers to solar power density, typically Watts per square meter or Btu. Packing factor is the ratio of array area to actual land area for a system. Capacity factor is defined as the ratio of average load on an electricity generating unit to the capacity rating of the unit (USDOE EERE-Solar Energy Glossary). Nearly all transmission lines associated with large solar projects will need to be upgraded. These updates will cause additional habitat disturbance great distances from project sites (Solar Done Right, 2010).

Negative impacts from land use may be similar to those of the wind farms. Additional effects may also be present, such as “habitat fragmentation; interference with migration corridors; reduced access to watering holes; increased edge effects (e.g., introducing nonnative, invasive or predatory species); changes in water flow patterns; interference with eolian processes (i.e., sand movement and dune formation); glare (for CSP systems); vehicular traffic; hazardous material release; and increased risk of fire” (Reimer and Snodgrass, 2010). Soil compaction, removal, and erosion occur during solar farm development. Parabolic-trough solar thermal plants require absolute removal of vegetation as well as grading to remove hills to contour uniform topography. Other designs such as ground-mounted photovoltaic arrays and heliostat-mirrors aimed at central power towers claim to be low-impact, but they too require vegetation removal around fixtures and for access roads (Solar Done Right, 2010).

In San Bernadino County, California the massive Ivanpah solar project utilized a low-impact preliminary design which would remove approximately 412,600 cubic yards of vegetation and 245,000 cubic yards of soil would be disrupted. Cryptobiotic crusts on the soil of desert ecosystems are composed of cyanobacteria, green and brown algae, lichens, mosses, liverworts, and fungi that play an essential role in soil stability, soil-plant-water relationships, nitrogen fixation, as well as providing nutrients for plants. These crusts are extremely slow to recover from disturbance due to the slow colonization of lichens and other mentioned species (Solar Done Right, 2010)

Desert sites have rich, diverse biological resources including rare plant communities. These communities contribute to climate stability, soil preservation, and watershed maintenance and flood control. Project designs destined for flood plains will need considerations such as berms, artificial cement channels, detention basins, and soil-cementing, which will increase habitat alterations and mitigate negative environmental impacts (Solar Done Right, 2010).

Although several areas of the United States are being examined as potential solar farm sites, the ideal location is the sunny southwest desert. In addition to precious water consumption in an already arid environment, solar farms will impact the ecosystem through species mortality and habitat disturbance. Solar power development impacts on the desert ecosystem are greater than non-location-dependent projects. Solar must be placed where solar resources are optimal, whereas other energy projects may be able to be relocated to avoid sensitive species disturbance. The desert is the home to many species listed on the Migratory Bird Treaty Act (MBTA) or listed or petitioned to be listed on the ESA including the desert tortoise, Mohave ground squirrel, the burrowing owl, pygmy rabbit, greater sage-grouse, and Amargosa toad (Reimer and Snodgrass, 2010). Additional sensitive species in this range include the golden eagle, Gila monster, bighorn sheep, LeConte’s thrasher, Mojave fringe-toed lizard, flat-tailed horned lizard, and several rare plants (Solar Done Right, 2010).

The threatened desert tortoise is frequently in the spotlight of species conservation with regards to solar farm development because its environment most frequently overlaps prime solar development locations. The Ivanpah project required 4,073 acres of land, all of which are home to the desert tortoise. The environmental impact statement for the project calls for “pre-construction tortoise clearance surveys, translocation of a minimum of 25 tortoises, installation of tortoise exclusionary fencing, a 3:1 compensatory mitigation ratio requiring acquisition and conservation of Mojave Desert tortoise habitat, and numerous other minimization and mitigation measures (Reimer and Snodgrass, 2010).”

Animal translocation has had limited success, especially for reptiles and amphibians (Lovich and Ennen, 2011). Translocation of tortoises causes behavioral pattern changes that increase their exposure to stressors and affect their ability to survive (Farnsworth et al., 2015). Stressors include altered thermoregulatory responses, increased predation risk, and exposure to diseased resident tortoises. Farnsworth et al., (2015) explain that few studies have examined the effects of tortoise translocation over several years and best practices for translocation distances are undetermined. In 2011, Lovich and Ennen commented that there are few mitigation alternatives for desert tortoises and other protected species aside from relocation. Additional studies are necessary to improve the conservation and management of this species, among others, due to renewable energy development (Farnsworth et al., 2015).

Migratory birds are also an issue for solar developers, as solar farms may remove nesting or other habitats. Destruction of migratory bird habitat without directly taking a bird, nest, or eggs, is not protected by the MBTA, but direct injury or mortality of migratory birds is.  Species that are typically impacted by solar developments include the burrowing owl, golden eagle, Brewer’s sparrow, and loggerhead shrike. Mortality of migratory birds by solar energy sites includes: “(1) collisions with communication towers, transmission lines, power towers, and other elevated structures; (2) electrocution on transmission lines; (3) contact with toxic salts in evaporation ponds; and (4) burns from contact with the reflected sunlight between the mirrors and the power tower” (Reimer and Snodgrass, 2010).

The Ivanpah facility, among other solar farms, was noted in popular media for its effects on avian species that fly into the radiation range. As birds fly into the solar radiation field, they are stripped of moisture and instantly ignite. The name “streamers” has been given to these unlucky birds to describe the smoke trail following the ignited animals. The Ivanpah system causes approximately one “streamer” every two minutes. The Crescent Dunes Solar Energy Project in Tonopah, Nevada is expected to produce about one-eighth of the total energy output of the Hoover Dam. This system was tested for roughly two hours, concentrating solar energy on a point of the center tower, 1,200 feet off the ground. During testing an estimated 130 birds were injured or killed. The Ivanpah system is older and is over 10 times the size of the Crescent Dunes system. Stallard explains that the streamers are caused by a chain of attraction: insects are attracted towards the mirror’s bright light, which then attracts the insects’ predators (Stallard, 2015).

A major issue specific to CSP solar farms is water consumption in what is typically an arid climate. CSP is a thermoelectric generation technology, meaning water is heated to make steam to drive turbines. The cool-down process needed for the excess heat generated requires water, as much as 800 gallons per MW (Reimer and Snodgrass 2010). According to an article by Solar Done Right in 2010, additional water needs include potable water for power plant workers and wash water for the mirrors. The Ivanpah system uses approximately 6 million gallons of water per year for mirror washing.

Solar thermal plants utilize evaporation ponds for generator cooling. Chemicals used for rust control accumulate in the ponds and run the risk of entering groundwater supplies (Solar Done Right, 2010). A solar facility in the Mojave Desert of California used water containing selenium for steam production. Although the amount was determined to be non-toxic, bioaccumulation of selenium may occur as the wastewater is continually pumped into the evaporation ponds (Lovich and Ennen, 2011). Similar to a solar facility’s mirrors, insects are attracted to the water, which then attract birds for feeding purposes. Another site where concerns were raised is the Genesis solar plant, a 1,950 acre solar plant in Blythe, California. In 2014 it was investigated by the FWS for the death of 64 birds in its wastewater evaporation ponds. The birds were coated in an oily, heat-transferred fluid that made its way into the ponds (Danelski, 2014). Aquatic species listed with or without limited ranges pose a significant issue to solar development. Potential listings, such as the Amargosa toad in Nye County, Nevada, may cause project relocations or cause developers to consider alternative technology that includes water-limiting designs (Reimer and Snodgrass, 2010).

1. **Geothermal Energy Effects on the Ecosystem**

Geothermal energy is derived from the earth either by underground reservoirs of hot water or steam or subsurface areas of dry hot rock with the assistance of cool water injections. Wells are drilled into a reservoir in order to bring the heated water or steam to the surface. Heat energy is converted to electricity through one of three ways: flash steam, binary cycle, and dry steam. Flash steam plants utilize hot reserves of water (>360 degrees Fahrenheit) that are under high pressure underground. As the water is pumped towards the surface, it vaporizes into steam. Binary cycle plants use geothermal reservoirs that are cooler, at roughly 165-360 degrees Fahrenheit.  The water is pumped to the surface and transfers its heat to a liquid that has a lower boiling point, which then vaporizes to drive an electric turbine. Dry steam plants use the hottest, and rarest, underground reservoirs of steam that are roughly 455 degrees Fahrenheit or hotter. In this technology, the water is already in vapor form, so it is directed to the surface where it is directly used to drive an electric turbine (Reimer and Snodgrass, 2010). Non-electrical uses for geothermal energy include utilizing the warm water heat for drying timber, cascading to improve the efficiency of a resource, and heating small-scale greenhouses (Stewart, 2012).

In comparison with coal or nuclear plants, geothermal plants have a small footprint. Geothermal systems take approximately one to eight acres of land per MW generated, whereas coal plants take five to ten acres and nuclear sites take 19 acres per MW generated. The typical acreage of disturbance for geothermal resource development phase ranges from 53 to 367 acres (U.S. Bureau of Land Management and U.S. Forest Service, 2008). Most geothermal plants tend to have a low visual profile compared to wind, solar, nuclear or fossil-fuel plants (DiPippo, 2012). Fuel for coal and nuclear plants can be transported to generation sites to avoid impacts on sensitive lands, whereas geothermal plants are most economically beneficial to be located as close to the resource as possible. Technologies have been developed to improve the footprint size such as slimhole and directional drilling, which allow for less land required for drilling and exploitation of many resources from a single location, respectively. Habitat disturbance caused by geothermal projects are similar to other energy developments, including both renewable and nonrenewable. These effects include habitat fragmentation, injury or mortality of species, introduction of invasive species, noise, and release of potentially hazardous materials (Reimer and Snodgrass, 2010).

Geothermal exploration is done through leasing of sites that can range in size from 640 to 5,120 acres ( U.S. Bureau of Land Management and U.S. Forest Service, 2008). Public land is leased according to BLM through the Geothermal Steam Act (GSA) which “establishes a competitive leasing procedure, mandatory rents and royalties, and lease size” (Reimer and Snodgrass 2010). Although the GSA prohibits leasing on sensitive habitats, it also allows the lessee to utilize as much of the land as the Secretary deems necessary for energy production. According to Glassley (2015), geothermal power has the smallest land-use impact per MW generated of any energy conversion technology other than nuclear power.

In 2008, the U.S. Forest Service, along with BLM, finalized a Geothermal Leasing PEIS to streamline geothermal site leasing and analyze its environmental effects. The PEIS states that although no direct impacts are made on the environment through an issue of a geothermal lease, the commitment of the resource for potential exploration, drilling, utilization, reclamation, and abandonment is of concern (USBLM and USFS, 2008). The PEIS determines “(1) the identification of public lands with geothermal potential as being open or closed to leasing; (2) the issuance of geothermal lease applications pending as of January 1, 2005; (3) development of a comprehensive list of stipulations, best management practices, and procedures to serve as consistent guidance for future geothermal leasing and development on public lands; and (4) amendment of BLM land use plans to adopt resource applications, stipulations, best management practices, and procedures for geothermal leasing” (Reimer and Snodgrass 2010).

The Geothermal Leasing PEIS discloses that GHG emissions, and other suspected climate change factors, will result from exploration and development activities (U.S. Bureau of Land Management and U.S. Forest Service, 2008). Geothermal fluids contain dissolved gaseous hydrogen sulfide and carbon dioxide which are harmful to people working at geothermal sites and may be an issue in urban areas and attribute to climate change. In Rotorua, New Zealand, hydrogen sulfide in motel rooms and hot pool enclosures have been attributed to numerous poisonings and deaths (Stewart, 2012).  Some of these emissions will be naturally sequestered and some will accumulate with GHG concentrations already in the atmosphere. Ultimately, geothermal energy has a lower carbon output in comparison to nonrenewable energy sources. Therefore, geothermal energy projects can result in a net decrease in GHG emissions if it helps reduce the reliance on fossil fuel-based power production. Other environmental impacts of geothermal energy tend to be of higher concern.

Geologic disruptions may cause seismic activities and related ecosystem changes (U.S. Bureau of Land Management and U.S. Forest Service, 2008). Induced seismicity is caused by a change in fluid pressure within a stressed rock formation, which leads to movement of the rocks and associated surface movement (DiPippo, 2012). The U.S. BLM and Forest Service explain that seismic risk is more likely to impact geothermal facilities than the operation of these facilities is to cause seismic activity. DiPippo (2012) states that almost all geothermal fields under exploitation have experienced induced seismicity, but it is highly improbable that exploitation would lead to a major earthquake. High pressure fluid injections into fault zones have shown to increase seismic activity. These cases utilize high pressure injection of fluids from outside the geologic system, which is different than geothermal fluid injections in normal settings. Geothermal fluid injection utilizes geothermal fluid withdrawn from the resource which is then used and re-injected into the system. The re-injection causes a near zero net pressure change, representing a lower risk of increasing seismic activity (Reimer and Snodgrass 2010). The emerging technology Enhanced (or Engineered) Geothermal Systems (EGS) may experience issues with seismic risk due to the critical need for high pressure re-injection. In 2007, EGS technology resulted in a magnitude 3.3 earthquake in Basel, Switzerland (DiPippo, 2012). To best avoid seismic activity, DiPippo recommends collecting baseline data at the site prior to drilling to understand the existing geologic and tectonic conditions.

Landslides may be induced by geothermic activities because geothermal plant sites typically lie in rugged volcanic terrain that are prone to natural landslides. The causes of the landslides are somewhat unclear. In 1991 at the Zunil field in Guatemala, at least 23 people were killed by a landslide that released approximately 106 m3of earth. The landslide was considered to be a result of the unstable equilibrium due to the steepness of the slope, the great amount of hydrothermally altered rock, and the site proximity to the Zunil fault. The studies associated with this disaster recommend future developers to consider “(1) development of a hazard map identifying all potential landslide areas, (2) slope monitoring instrumentation, (3) monitoring of springs for changes in flow rate, temperature, chemistry, and clarity, (4) installation of drains in slopes to remove moisture, and (5) avoidance of obvious unstable areas for wells, roads, and other construction activity” (DiPippo, 2012).

A major ecosystem impact specific to geothermal energy is water use. According to Stewart (2012), extracting geothermal fluids for power generation removes heat from reservoirs at over 10 times their replenishment rate. The flow path of water at geothermal sites is generally as follows: high-pressure mixed steam and liquid flow from the wellhead to the separator; high-pressure steam is separated from condensed liquid and piped to the turbine; steam expands into the turbine, dropping in pressure and temperature with some condensation; condensate is separated from steam as steam flows through multiple turbine stages; steam exits the turbine through the turbine exhaust and is condensed in the condenser; condensed water from the condenser is cooled in the cooling tower; cooling towers spray water into flowing air to result in evaporative cooling (Glassley, 2015). During this process, 60-80% of the steam that enters the turbine will end up evaporating into the atmosphere. This is a significant challenge to maintaining mass balance, therefore the fluid that remains after the evaporation process is re-injected.

Geothermal resource sustainability depends on the replenishment of extracted fluid, which varies from a few hours to several years to accomplish naturally. Re-injection is critical to maintaining fluid balance. If the extraction rate and replenish rate are both high, the extraction of water from other resource reservoirs may occur which may lower the local water table, reduce geothermal surface manifestations (hot springs and geysers), among other effects. If the extraction rate is higher than the replenish rate, reduced geothermal resource productivity and land subsidence may occur (Glassley, 2015). One of the most dramatic occurrences of land subsidence due to geothermal resource depletion was seen at the Wairakei geothermal field in New Zealand. Exploitation of the water reserves caused the ground to sag 3 meters in some areas and the hot spring and geysers died out as a result. The center of the subsidence area sinks at a rate of almost half a meter every year. The tourist site suffered as New Zealand’s popular Champagne Pool, a blue-tinted boiling spring, and the Wairakei geyser diminished. The ground continues to move sideways as it sinks towards the center, putting a strain on pipelines, buildings, and roads (Stewart, 2012).

Some geothermal plants discharge their waste fluid, but as previously mentioned, most plants re-inject the fluid into the ground. If the re-injection is not performed properly and is released on the surface, the waste fluid containing elevated levels of arsenic, mercury, lithium, and boron can cause environmental issues. Contact of this water with surface rivers or lakes may damage aquatic life and contaminate water that could be used for drinking or irrigation. The Wairakei site has released geothermal wastewater into the Waikato River that has strongly contributed to an arsenic level that almost always exceeds the World Health Organization’s standard for drinking water of 0.01 parts per million (Stewart, 2012).

The release of warm water can also increase the temperature of surface waters. Population mortality of aquatic and riparian species may occur, as they and their eggs are typically intolerant to temperature changes. In addition, waste fluid contains high mineral concentrations which can add dissolved metals and alter mineral and chemical content of surface water, thereby affecting the species within the associated streams (Reimer and Snodgrass, 2010).

Geothermal plants have not been as much of a concern for species-related issues as other renewable energy systems. It has yet to be determined whether this is due to a lack of research, if the technology is in fact more environmentally friendly than other renewable energy sources, or if the technology is too sparse at the moment to make conclusions. Conflicts may yet increase as additional projects are created. ESA-listed species have imposed limits on geothermal plants, but no high-profile species of concern are affected for now. Most environmental impacts of geothermal energy are due to habitat disturbance from development of wells and the power plant itself (Reimer and Snodgrass, 2010).

Geothermal developments have directly resulted in or contributed to the listing of numerous rare species. In Harney County, Oregon, the Borax Lake chub was emergency listed due to geothermal development in and around the lake. The chub is located only in the Borax Lake and its surrounding wetlands, therefore its survival was dramatically threatened by geothermal developments in the area. The Carson wandering skipper is an insect that was threatened by geothermal development in Washoe County, Nevada and Lassen County, California. Exploratory drilling was determined by the FWS to cause ground and hydrologic disturbances that may affect the skipper and its habitat. The BLM had leased rights in the borax Lake area according to the GSA, however the FWS expressed concerns that exploratory drilling could drain the lake or cause temperature or pressure changes in the associated aquifer. Ultimately, the Steens Mountain Cooperative Management and Protection Act of 2000 carved out an area for the skippers, which included Borax Lake, to prohibit geothermal leasing. Delisting criteria includes the development of an adaptive management plan of human land use to improve habitat quality (Reimer and Snodgrass, 2010).

Although animals tend to be the main focus of species conservation, not all ecosystem impacts revolve around them. At the Steamboat Hot Springs in Washoe County, Nevada, Steamboat buckwheat was listed by the ESA as endangered due to “potential threats of drilling for geothermal development, recreational and commercial development, and mining activities” (Reimer and Snodgrass 2010). Steamboat buckwheat is a rare plant that is located only in this region, but its listing did not prohibit geothermal development in the area. Ormat Technologies Inc. holds a thirty-year lease for geothermal power production on about half the land where Steamboat buckwheat naturally occurs. The Nature Conservancy reached an agreement with the original geothermal development company to protect the Steamboat buckwheat during their tenure. Ormat Technologies Inc. continues to honor this agreement along with the Nevada Division of Forestry.  An interesting finding in the FWS five-year review of the Steamboat buckwheat was that “[g]eothermal development of the site where the single population occurs was previously considered to be in conflict with the conservation needs of the species, but is now considered to have provided additional protections to the habitat that would not now be in place had the area been converted to urban/residential use rather than industrial (Reimer and Snodgrass 2010).

1. **Biomass Energy Effects on the Ecosystem**

Bioenergy refers to energy derived from recently living matter such as straw, wood, or animal wastes. These materials can be burned directly as solids for heat or power, which is called biomass, or can be converted into liquid biofuels. Solid biomass fuel is primarily used for heat or electricity generation (Spellman, 2012). Biogas, such as methane captured from the process of controlled aneaerobic digestion, can also be combusted to generate biopower (EESI).

A little over 100 years ago, the vast majority of the United States’ energy was based on biomass sources.  In the 1920s, the U.S. began to shift towards the use of fossil fuels as its primary energy resource. In most cases, it is more economical to utilize fossil fuels than plant matter (Spellman, 2012). Currently, biomass contributes 10-12% to the world's’ energy use, which is approximately ⅓ of the world’s current consumption of conventional energy (Colantoni et al., 2016). As technological advances are made, environmental concerns of GHG emissions rise, and fossil fuel supplies dwindle, biomass is becoming more appealing as a renewable energy source. Advances in conversion systems such as pyrolysis, ultracentrifuges, and the use of enzymes and microbes are decreasing the costs of extraction of plant resources for energy (Spellman, 2012).

The two most common sources of biomass are forests and agricultural areas. Colantoni et al. (2016) state that the interaction between exploitation of these sources and land conservation are the major factors of biomass energy sustainability that must be considered. The authors continue by stating that “a bad system of production and use of renewable sources can be just as harmful to the environment as fossil fuel.” When considering exploitation of biomass energy, developers need to plan for geological and climatic characteristics of the area, crop economics, and environmental degradation. Excessive removal of organic matter has negative impacts on soil quality. Biomass production decreases when the quality of soil is degraded, such as a loss of humus and residual fertility. Alterations in the cycle of organic matter must be avoided when by-products and residues from agriculture, forestry, or agro-industrial sources are utilized (Spellman, 2012).

As an example, complete removal of forested areas, or simple thinning of forest stands, raises questions about the costs versus the benefits of biomass energy production. Plants provide aesthetic, medicinal, recreational, air quality, water quality, and erosion control benefits. Forests act as carbon dioxide sinks and keep soil in place so that its contents do not contaminate streams. In some areas, particularly the dry interior western U.S. forests, biomass accumulates faster than it can decompose. Spellman notes that 39 million acres of National Forest land is threatened by wildfire due to unnatural fuel accumulations from ecosystem alteration. Spellman (2012) explains that increasing forest health and lowering the risk of fire can be accomplished by selective thinning. Selective thinning allows less competition for nutrients and water for the remaining trees and can provide for a sustainable energy use of biomass. However, thinning can result in damage to residual trees as they become susceptible to increased wind speeds, causing limbs to break and fall which may cause additional forest fires (Spellman, 2012). Western ponderosa-pine-dominated forests were originally open, low-density stands. Upon European settlement in the United States and utilization of the forests for energy, the forest shifted to closed, high-density stands. This shift has been detrimental to the vigor of old-growth trees. Spellman (2012) comments that it is vital to be selective with forest thinning, otherwise the resource will weaken.

Ecological succession occurs after both natural and unnatural disturbances. Thinning and forest biomass removal causes an increase in understory plant biomass and biodiversity. Removal of overstory stand structure increases light penetration through the canopy. New habitat niches become available and are colonized by invasion. Small mammals recolonize disturbed areas but diversity and species dominance through succession are altered from the original hierarchy. A major concern with thinning or biomass removal is the introduction or increase of invasive exotic species. Spellman (2012) reveals that many studies have shown a greater frequency or abundance of alien species in thinned stands. This alteration causes forest management concerns, increases costs, and can last for decades.

Overstory clearing comes at a cost to species that once benefited from this range of the forest. Cavity-nesting species, such as woodpeckers and flickers, as well as raptor species that use dense canopies for nesting are negatively affected. The endangered Mexican spotted owl and northern spotted owl require restoration treatments of thinned overstories. Spellman (2012) believes that amphibian response to a reduction in canopy cover will be negative because of the increase in light penetration, creating unfavorable warmer and drier conditions for species that require moist soils and decomposing wood to maintain water balance (Spellman, 2012).

Due to the large ranges of carnivores, there are informational gaps on carnivore responses to biomass forest clearing or thinning. It is known that a loss of denning habitat and prey population changes result from clearing projects and management. The American marten and fisher are indicator species that are sensitive to overstory removal. Black bears are associated with mature forests with downed wood and dense thickets of shrubs. Insects found in downed wood consist of 25% of their diet. Large, hollow logs are utilized for denning. Black bears also benefit from dense canopies for safety while resting and traveling. All of these elements are utilized in thinning practices.Ungulates such as deer, elk, mountain goats, moose, and bighorn sheep utilize dense forested areas for thermal cover and safety from predators. Wintering ungulates may be forced to lower elevations due to thinning which increases human-wildlife conflict (Spellman 2012).

Removal of biomass causes habitat fragmentation and species extirpations. Middle-aged, pole-sapling, or young forests are utilized less by wildlife than are older forests.  Species responses to various biomass management practices have been variable. The inability to determine management practices that allow retention of critical habitat elements is a concern for conservationists. The most important part of this retention is slow recovering elements that come from later stages of succession such as large-diameter downed wood and snags. Few studies have been conducted on the effects of forest thinning on reptiles. Many reptile species such as lizards prefer forest floor cover and downed wood for shelter. Spellman (2012) also suggests that additional long-term observational studies are needed at multiple spatial scales in order to more accurately determine habitat and species effects.

There are several environmental benefits to utilizing biomass for energy. Much like the other renewable energy sources discussed in this paper, biomass reduces greenhouse gases when utilized instead of fossil fuel burning. As biomass is burned for energy, carbon returns to the atmosphere as carbon dioxide. New growth of plants and trees replaces the biomass burned and removes carbon dioxide from the atmosphere. Processing of biomass may utilize fossil fuels, but the amount is negligible compared to sole fossil fuel use for energy. Natural forest decomposition releases methane into the atmosphere. Biomass-derived methane can be used to produce energy and reduce the amount released into the atmosphere.  When agricultural residue such as grass seed straw is burned, particulate matter and other air pollutants are released into the atmosphere. Instead of burning, the residue can be used as biomass fuels in combustion boilers to produce heat, steam, or electrical power (Spellman, 2012).

However, biomass energy production leads to land use and management changes that have caused GHG emission concerns. Several practices associated with biomass energy production cause direct and indirect emissions of carbon dioxide, methane, and nitrous oxide. Direct emissions result from land clearing, management practices used to harvest a biomass crop, and agricultural inputs (e.g. fertilizers). When land that was once used to produce food crops now produces biomass energy crops, land compensation is needed to replace the lack of food crop production. Grasslands, forests, and other ecosystems are cleared for agricultural use in producing food crops. This addition is responsible for indirect emissions, which are difficult to quantify or attribute to a specific land use change (EESI). In addition to emission concerns, world food supply and farm sustainability are critical for survival of the ever increasing human population. As previously noted by Pimentel (2008), the earth has less than half of the cropland per capita needed for a diverse diet and adequate essential nutrient supplies. This is particularly alarming when considering the production of ethanol from corn and other feedstocks. In 2000, 630 million bushels of corn was used in the United States for the production of alcohol for fuel use. Application has increased dramatically, to a use of 5.175 bushels in 2016 (USDA-ARS, 2016).

1. **Hydropower Effects on the Ecosystem**
   1. **Conventional Dams and Run of River Systems**

Hydropower involves the use of kinetic energy of flowing water to create power. A dam or diversion structure alters the natural flow of a body of water to capture the energy. Similar to other energy production, turbines and generators convert the energy into electricity. Hydropower is relatively easy to obtain, is cheap, and is widely used. Every state in the U.S. except for Delaware and Mississippi use hydropower for electricity (USDOE EERE-How Hydropower Works).

Economic and environmental factors are carefully considered when developing a hydroelectric power station. Plants are typically either large with a substantial energy storage capability or are smaller and have minimal or no storage capability. The larger versions are almost all reservoir hydroelectric plants which are located in an upland or mountainous region. The reservoir accumulates water during the wet season and drains in the dry season. Tunnels and penstocks deliver water to the turbines, creating power throughout the year. The smaller versions are run-of-river designs constructed of weirs which take advantage of the instantaneous state of the river they are located on by powering the turbine directly. Some run-of-river designs include a pond with limited capacity to alleviate short-term flow variation at the turbine (Munoz-Hernandez et al., 2012).

In addition to continuous power supply, reservoirs provide a water supply for other agricultural and industrial uses as well as flood control uses. However, impoundment of free-flowing water has negative impacts associated with its restriction. Healthy river ecosystems provide groundwater recharge, pollution abatement, and water reclamation. Reservoirs prevent the free-flowing habitat of river ecosystems including the blockage of fish migration and creating a reduction of water quality within and downstream of the reservoir (Jager and Smith, 2008).

At hydropower sites, fish typically crowd below the dam wall, unable to swim upstream for reproductive and other life cycle purposes. Technologies called fishways or fish passes, such as ladders, lifts, bypasses, locks, channels, and trap-truck systems, assist migratory fish to move upstream (Pelicice et al., 2015).  Kirk et al. (2015) studied the behaviors of adult Pacific Lampreys at the fishways of the Columbia River dams in Washington State. The Pacific Lampreys were observed as having difficulties reaching the upstream water through the fishways. Higher tail-beat frequencies of the Pacific Lampreys and higher water velocities were observed near the fishway entrances. The authors concluded that the Pacific Lampreys were exerting greater effort at these locations. Additional observations at fishway entrances at other sites along the river included poor attraction flow, presence of predators, and long-distance challenges (Kirk et al., 2015).

Downstream movement of aquatic species is partially blocked if the species do not utilize the turbines or spillways. Pelicice et al. (2015) theorized that large reservoirs impede downstream movement of fish. Similar to upstream movement, reservoirs affect migratory movements of species and partition the habitat. The dynamics of the reservoir barrier is different than that of the dam. Reservoirs extend both longitudinally and horizontally over a large distance, are not distinct physical structures, and have gradual transitions of both still and flowing water. The fish experience a hydrological obstacle from downstream movement due to the conditions of depth and water velocity being different within the reservoir from that of adjacent river reaches. These effects take place in large reservoir systems and do not affect small weir systems (Pelicice et al., 2015).

Small hydropower plants are less researched than larger plants and do not contain large reservoirs, but similar ecosystem impacts are reported downstream because water diversions alter the natural flow of the river. Small system studies have revealed changes in species composition, an increase in opportunistic species, and a decrease in density and biomass of fish. Environmental stressors impact fish metabolisms, growth, reproductive potential, and resistance to diseases. Benejam et al., (2016) investigated impacts on fish populations downstream from 16 small hydropower plants in the Ter river basin in Catalonia, Spain. Impacted areas had lower water depth, less refuges for fish, higher abundance of pools, lower abundance of riffles, poorer habitat structure, and less macrophytes than upstream control sites. Fish abundance and average length and weight were lower downstream of the hydropower plants. Species abundance differed between the upstream and downstream sites, with more loach and barbel and less brown trout and minnows in the downstream region. Brown trout, a species intolerant to poor water quality and habitat structure, was the fish species that showed the greatest impact between the two sites (Benejam et al., 2016).

In addition to species affects, converting shallow river and lake areas into deep reservoirs has other consequences. Macrophyte plants in these once shallow regions that are cleared will result in a loss of a CO2 sink. Forest that is not removed becomes submerged and stores large amounts of organic carbon. Methane is released by bacterial decomposition of the organic carbon in the submerged trees, plants and soil. Sediment flow becomes blocked and the aquatic ecosystem becomes fragmented. The variable pulse of rivers occurs naturally with the fluctuation in rainfall and river dynamics between linked rivers. Species utilize the river pulse for their life events such as migration, reproduction, and metamorphosis. Disturbance to the pulse causes disruptions to the triggers that cause these life events to occur. Local level extinction of species may occur when dams cause fragmentation and species are unable to reach connecting rivers and lakes (Kahn et al., 2014).

Reservoirs have a high potential to become eutrophic and low in dissolved oxygen, killing species with low tolerance to low oxygen levels in the reservoir and downstream (Jager and Smith, 2008). Reservoirs increase the width of water bodies and create large, shallow littoral zones where light can penetrate and warm the water. Aeration is reduced by the thermal stratification and oxygen levels are reduced. Waterborne diseases, such as schistosomiasis and malaria, occur more frequently at these sites (Gunkel, 2009). Habitat diversity is decreased as a result of the hindrance of natural geomorphological processes by the altered water flow schedule (Jager and Smith, 2008). Sedimentation within the reservoir causes a loss of nutrients. During flooding events, agricultural areas downstream will not be fertilized due to the lack of nutrient availability (Gunkel, 2009).

Greenhouse gas emissions of CO2 increase with eutrophication of reservoirs. Anaerobic conditions include rising emission of CH4 as the lake reaches higher trophic levels (more eutrophic, or nutrient-rich). Energy density can be used as a tool for evaluating the greenhouse gas emission potential of a reservoir. Energy density is mainly determined by a reservoir’s morphometry and is the ratio of the reservoir surface and the hydropower generation capacity. The energy densities of some reservoirs in Petit Saut, French Guinea point to an alarming emissions potential higher than that of coal energy production (Gunkel, 2009).

Additional changes after the hydropower plant is operating can result in ecosystem damages. Operational water level changes of up to several meters can damage littoral zones, leading to a poorly buffered ecosystem. The change from running water with transverse nutrient transport by flow to standing waters causes these areas to be at risk of trophic upsurge, or eutrophication within dammed rivers (Gunkel, 2009). Optimal flow releases, which maximize energy production while meeting water demands, result in detrimental impacts to the ecosystem (Jager and Smith, 2008). An increased risk of flooding occurs when sediments build up in the suspended load of the inflow area. Sedimentation causes a loss of nutrients within the reservoir, causing no fertilization during flooding and a decline in soil fertility (Jager and Smith, 2008). Rapid depressurization of the water that flows through the turbines can cause significant increases in GHG emissions downstream (Kahn et al., 2014).

* 1. **Tidal Energy**

Gravitational forces from the moon and sun pull waterbodies on and off of the coastlines, creating tides. The most noticeable locations of these tides are coastlines, but this movement is not great enough for the turning of a turbine. Few areas exist where geographical conditions are such that the tide rushes in and out with the force of a small river. As the tide comes in, a dam holds back the water until maximum depth, then the dam opens to release the water. Power production is limited because it can be produced only four times a day, twice at high tide and twice at low tide (Newton, 2011). However, tidal power has a roughly 80% efficiency rate compared to that of coal and oil which is approximately 30% (Green the Future, 2008).

Tidal energy utilizes the wave motion of the ocean’s swells to produce electricity. Generators are placed underwater and act as windmills, turning as the tides move. Costs associated with the development and extraction of power from tidal turbines is exceedingly expensive and is currently uneconomical compared to other renewable sources. “Wave energy costs at least 20 cents per kilowatt hour to generate, compared with 4 cents per kilowatt hour for wind power” (Ma, 2011). However, Ma (2011) notes that wind energy was significantly more expensive years ago. Continued research and development may decrease the costs of tidal power in the future, making it a more viable option.

In 2011, tidal energy research and development slowed due to environmental impact concerns. There are many unknown impacts to the coastlines and associated species, such as sediment deposition or migration alteration, that concern both developers and conservationists. Tidal energy buoys are suspected to alter ecosystems and disrupt whale and fish migration, reducing access to fishing sites. Currents and their natural movement of sediments can be altered by buoys, changing the shoreline. Large buoys could attract more fish, but cascading effects may occur as more predatory species are attracted to the site. Electromagnetic cables on the ocean floor may also affect sea life (Ma, 2011). Deadly ship strikes of whales and dolphins account for approximately 47% of recovered carcasses. There is concern that large rotating turbine blades of tidal energy generators will have similar impacts (Macaskill, 2011). Marine life studies aid in determining which sites are the best candidates for tidal projects (Ma, 2011).

American Public Power Association members, Tacoma Power and Snohomish County Public Power District in Washington State, evaluated a tidal development test site in the Puget Sound (Ma, 2011). Admiralty Inlet was selected as the site for Snohomish County PUD’s test project, but the project came to a halt when funding dried up (Flatt, 2014). At this site, The National Research Lab explored the potential effects the proposed tidal energy turbines would have on the endangered Southern Resident Killer (orca) Whales.  The turbines were to be placed at 55 meter depths, below that of the typical range of the orcas. Orcas have highly evolved acoustic sensory capabilities which would enable them to detect and avoid the turbines. It was determined that because of their sensory capabilities and that they spend 97% of their time in the top 30 meters of the water in the Admiralty Inlet, the orca collision rate with the turbines was negligible (Carlson et al., 2014). This study was focused on one endangered species, leaving other species and ecosystem effects undetermined.

A tidal power plant in the Shihwa Lake in Korea was studied to determine the sediment deposition effects of the plant. Manila clams were transplanted in the study to evaluate the bioaccumulation of heavy metals in the species due to the tidal plant operation. A significant amount of copper, zinc, lead, chromium, and cadmium accumulated within the clams after 56 days of relocation to the tidal power plant site (Ra et al., 2011). These authors suggested that the operation of the plant may have released heavy metals from sediment particles into the water body which caused bioaccumulation of these metals in the clams.

1. **General guidelines and mitigation options**

Urgency to develop renewable energy projects must be tempered with an awareness of the environmental impacts such projects may cause and the regulations that are involved. The most critical step in avoiding ecosystem impacts is proper site selection. Sites must be selected by developers based on ample resource availability. Solar projects deliver results in areas with the most sunlight, wind projects need wind, and so forth. Locations with the best resources tend to overlap areas with sensitive or protected species. Developers should search FWS databases to collect data and make the best judgement call from their research. Although avoiding protected species habitat is ideal, it is not practical in many cases and the developer must evaluate the best way to avoid the most sensitive areas (Reimer and Snodgrass, 2010). Programmatic Environmental Impact Statements and Before-after-control-impact assessments are useful tools for developers to determine ecosystem effects that a habitat will experience from energy developments. Programmatic Environmental Impact Statements focus on actions that may cause GHG emissions, carbon sequestration, and climate change (U.S. Bureau of Land Management and U.S. Forest Service, 2008). Before-after-control-impact assessments determine the impact that energy infrastructure has on wildlife (Shaffer and Buhl, 2016). More studies with regards to renewable energy production need to be conducted in order for wildlife and environmental specialists to effectively plan for energy developments and perform effective mitigation efforts.

Developers should have early and frequent contact with permitting agencies in order to streamline development. Once a project site is located, early contact with the land management agency (e.g. BLM, the Forest Service, or other agencies) should be made if the project is on federal land managed by one of these agencies. The parties should discuss all resource issues up front in order to get a better idea of the agency’s concerns and future mitigation needs. The appropriate federal agencies will need to engage in Section 7 consultation under the ESA with the Service if listed species or their critical habitat are located on the proposed site.  Section 7 consultation involves collaboration between the developer and the federal permitting agency to prepare a biological assessment as the agency’s designated non-federal representative. Involvement of the developer in the consultation will give him or her a better idea of what measures the federal permitting agency is considering. If the project site does not involve a federal nexus, the developer should coordinate with the FWS early to prevent any issues with Section 9 (Reimer and Snodgrass, 2010).

Developers should consider taking voluntary actions to reduce impacts. Doing this at the project start may increase costs to construction and/or implementation up front. The caveat is that measures taken up front to reduce environmental impacts can save both valuable time and costs in the long run. Time and increased costs for mitigation efforts can result from additional permitting and litigation challenges mid-project. Examples from Reimer and Snodgrass (2010) include designs to “avoid riparian areas or wetlands that may attract raptors, and designing power lines to minimize raptor electrocutions” in wind projects.

Reimer and Snodgrass (2010) also suggest preparing a habitat conservation plan (HCP) covering an ESA listed species for projects that affect a listed species and do not involve a federal nexus. If the HCP is determined to be acceptable, “the Service can issue an incidental take permit that will protect the developer from liability if the species are harmed, injured, or killed by the project within the limits set forth in the permit” (Reimer and Snodgrass, 2010).

A developer should negotiate a Candidate Conservation Agreement with Assurances (CCAA) if the project site is not on federal land and contains a species that is at risk and may become listed. The CCAA requires the developer to implement conservation measures that would preclude the need to list the species in question if the measures are applied on all necessary properties. It also allows the developer to obtain an enhancement of survival permit under the ESA to protect the developer in that if the species in question is ever listed, that no additional conservation measures will be required by the developer and take of the species within the permit limits is authorized. Reimer and Snodgrass (2010) suggest that a CCAA may be effective in providing assurance to developers in the aforementioned greater sage-grouse or Amargosa toad habitat.

* 1. **Wind**

The Fish and Wildlife Service Wind Turbine Guidelines Advisory Committee developed tiered guidelines to better evaluate and minimize the risks associated with wind projects. The committee’s guidelines goals were to (1) aid wind energy developers in avoiding or minimizing the risks to wildlife and their habitat, (2) ensure that the applicable regulatory agency is educated on the impacts on and the options that prevent risks to the ecosystem, and (3) establish the baseline information required to review a wind energy project and determine the follow up needed post construction. The five tiered stages of guidelines are: (1) preliminary evaluation or screening of potential sites; (2) site characterization; (3) field studies to document site wildlife conditions and predict project impacts; (4) post-construction fatality studies; and (5) other post-construction studies. (Reimer and Snodgrass, 2010.) By utilizing these steps, wind developers can choose to proceed, modify, or abandon a project while maintaining a good rapport with agencies, expediting the approval process if applicable, and minimizing the impacts on the ecosystem (Reimer and Snodgrass, 2010).

* 1. **Solar**

Reimer and Snodgrass (2010) recommend an active relationship between solar developers and agencies to implement measures to reduce impacts on wildlife. Solar developers should work closely with the FWS to avoid incidental take on species. Pre-construction surveys for nesting bird species as well as no-disturbance buffers for active nests can be proactive ways of reducing avian disturbance (Reimer and Snodgrass, 2010). Careful consideration of topography and drainage patterns in arid climates can prevent negative impacts. Water runoff pathways that are altered during the development process have shown to minimize water availability and cause the habitat to support less biomass of perennial and annual plants (Lovich and Ennen, 2011). Dry-cooling designs or netting evaporation ponds can prevent birds from interacting with evaporation pond toxic substances (Reimer and Snodgrass, 2010). Dry-cooling systems, although not as economical and efficient as wet-cooling, consume 90-95% less water than wet-cooling systems. In the southwest United States, limited water resources such as the lack of permanent bodies of water and water regulation have increased the popularity of dry-cooling systems on public lands (Lovich and Ennen, 2011). The Devil’s Hole pupfish is an endangered species with a limited range of a single aquifer-fed cavern in southern Nevada. Solar Millennium, a German Developer, utilized dry-cooling technologies in its plans for its project in southern Nevada which prevented potential impacts to the Devil’s Hole pupfish (Reimer and Snodgrass, 2010).

Planning projects outside of migratory pathways, utilizing strobe lights instead of steady lights, and using shorter structures may reduce bird collisions with infrastructure. Increasing conductor wire spacing to distances greater than that of the wingspan of large species can minimize electrocution fatalities (Reimer and Snodgrass, 2010). Stallard (2015) notes that when the Crescent Dunes system used less mirrors during their second test, no birds were ignited when crossing the system’s radiation field. In addition, smaller power towers in Europe experience less “streamer” incidents. Additional research is needed to determine whether the size and type of technology or the location of the air paths that birds follow are to blame for these takes (Stallard, 2015).

A number of renewable energy projects, namely solar, are proposed for the California desert. The California Energy Commission, FWS, BLM, and California Department of Fish and Game (CDFG) have issued draft Interim Guidance for Desert Renewable Guidance which will provide recommended actions for resources affected by applications for renewable energy. Suggestions for project siting and design that will minimize ecosystem impacts and sensitive species are included (Reimer and Snodgrass, 2010).

DOE’s Office of Energy Efficiency and Renewable Energy and the Bureau of Land Management created a PEIS for solar farm development in Arizona, California, Colorado, New Mexico, Nevada, and Utah in order to evaluate utility-scale solar projects for environmental policy conformity and mitigation strategies (Reimer and Snodgrass, 2010). Seventeen utility-scale solar projects, totaling about 285,000 acres of public land, were approved by the Department of the Interior. The final PEIS estimates 23,700 megawatts from the 17 zones and variance areas (Federal Information & News Dispatch, Inc., 2012). The Solar PEIS is a road map for solar energy developers that can be used to identify preferred solar project locations and streamlining the National Environmental Policy Act process (Reimer and Snodgrass, 2010). Preferred solar project locations are characterized by “excellent solar resources, good energy transmission potential, and relatively low conflict with biological, cultural and historic resources (Federal Information & News Dispatch, Inc., 2012).” 78 million acres of land were excluded from the development sites in order to protect natural and cultural resources. In addition, the PEIS includes environmentally responsible development best practices (Federal Information & News Dispatch, Inc., 2012).

* 1. **Geothermal**

Fluid balance at geothermal sites is critical for maintaining a sustainable geothermal resource. An example of mass balance in geothermal energy can be found at the Geysers of Yellowstone National Park. Sustainability is achieved through an agreement with local water districts for disposal of their wastewater by injection at the geothermal reservoir. Not all sites are located near populations with wastewater disposal needs. An alternative way to balance mass would be to utilize surface water for areas that have an abundance of surface water. Sites located near coastlines or other nonpotable water sources could use those water resources for mass balance (Glassley, 2015).

Mishra et al., (2011) explain that mitigation efforts for water use by geothermal energy production have primarily focused on dry cooling systems at hydrothermal generation facilities. However, the energy penalty during hot months imposes a financial penalty at these facilities, which moderates geothermal electricity's advantage of providing power at the will of the operator without storing the potential energy, also known as “baseload dispatchability” without storage. This advantage is what makes geothermal energy desirable over other renewable energy sources (Mishra et al., 2011). Water use may be minimized at geothermal sites by using a hybrid approach that utilizes air cooling for the coolest part of the year. Development of hybrid cooling technologies are currently underway. In this practice, the resource would be at maximum efficiency at ambient air temperature ranges during the coolest season. During warmer months, air cooling will be supplemented by incremental water cooling. This approach will minimize evaporation losses during the warmest months.  To maintain geothermal resource sustainability and water availability for nonpower generation purposes, water-stressed regions will need to utilize advanced cooling technologies (Glassley, 2015).

* 1. **Biomass**

Forest-biomass energy production is controlled by statistical modelling. Statistics allow researchers to justify the implementation of a biomass program and determine various environmental parameters such as insect infestation or lightning-caused forest fires. Monitoring, sampling, and processing of forest-based biomass commonly involves variance. Program implementation is better determined when data is properly characterized through precision (variance), accuracy, and bias. The fuel value of forest resources is determined by the amount of heat energy that can be recovered. Recoverable heat energy varies among tree species, within a species, with moisture content, and with chemical composition (Spellman, 2012).

The economic viability of a biomass resource, even though biomass is readily available, is a major factor in its exploitation (Colantoni et al., 2016). In order for biomass to be a viable energy source with limited environmental impacts, it must be produced and harvested as sustainably as possible. Exploitation choices will determine the impacts on soil, water resources, ecosystem function, and biodiversity. These choices must be made in regards to land-management objectives such as forest stewardship, food production, farm preservation, and wildlife management. A low-cost way of reducing GHG emissions and other air pollutants is co-firing of biomass and fossil fuels (EESI). Another renewable energy combination that can result in lower GHG emissions is that of biomass gasification and compressed air energy storage (CAES) in wind energy production. Biomass is used in place of the fossil fuel requirement of CAES. Compressed air energy storage improves wind power reliability by eliminating wind power intermittency (Denholm, 2006).

* 1. **Hydropower**

Healthy river ecosystems experience a naturally varied flow rate. Benejam et al., (2016) suggest that the best way to improve stream ecology from hydropower impacts is to recreate the natural flow of the water body. Utilizing a natural flow regime for hydroelectric plants can recreate this flow variance and can be especially beneficial for the downstream habitat. Rivers with large diurnal fluctuations cannot maintain its ecosystem functions, such as providing a suitable habitat for rearing of juvenile fish, if its flow variance is not mimicked by the hydropower plant. Effective fish passes can mitigate species decline (Jager and Smith, 2008). Adding fish passes to all weirs, whether big or small, to promote connectivity along the river may aid in species richness (Benejam et al., 2016) However, Pelicice et al. (2015) report that most fishways have proven to be deficient and that habitat separation and species degradation still occurs. A solution for large reservoir barricading effects is difficult to create because reservoirs are not defined physical structures and have varied hydrologic flows (Pelicice et al., 2015).

On the other hand, eutrophic conditions of a reservoir can cause low oxygen levels downstream. Non-generating water flows not released through the turbines, or spill-flows, can aid in replenishing the dissolved oxygen content.  It is critical to find a balance between flow variance and meeting water supply constraints to maintain sufficient levels of dissolved oxygen and low levels of phosphorus, nitrogen, fecal coliform, and chlorophyll (Jager and Smith, 2008). Jager and Smith (2008) also suggest continued future research on the role of flow variability and its effects on ecological river health.

* 1. **Tidal Energy**

Marine species protection is critical in the development and operation of tidal energy. Concern of visual or sonar detection of the underwater turbines raises questions on the severity of effects wave energy will have on ocean species. The Scottish Association for Marine Species suggests possible solutions include fitting the turbines with pingers. Pingers emit sounds to deter marine life. Additional suggestions include protective netting to prevent collisions, warning lights on turbine blades, and turning off turbines during breeding seasons. None of these theories have been tested to date (Macaskill, 2011).

**Conclusion**

Converting energy into useful forms for humans, such as electricity, inevitably disturbs the ecosystem of the source. Researchers urge that “scientifically based monitoring, analysis, and mitigation efforts” be an essential part of all energy developments, even if they are intrinsically “greener” than conventional energy exploitation. Additional research on renewable energy development and operation as well as active management of these findings can reduce environmental impacts (Glassley, 2015). Environmental and species conservation plans must be developed for each site and tailored to each renewable energy source in order to be effective.

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